Broad-band High-Frequency Sound Interaction With the Seafloor

Nicholas P. Chotiros
Applied Research Laboratories
University of Texas at Austin
Austin, TX, 78713-8029
phone: (512) 835-3512 fax: (512) 835-3259 email: chotiros@arlut.utexas.edu
Award #: N00014-98-1-0062
http://www.arlut.utexas.edu/home.html

LONG-TERM GOAL

A physical model of high-frequency sound interaction with the seafloor including, penetration through the water-seafloor interface, propagation within and scattering from the seafloor.

OBJECTIVES

Resolution of modeling issues through experimental measurement of acoustic penetration into, and scattering from, a sandy bottom.

APPROACH

Ocean sediments consist of solids immersed in seawater and therefore should be modeled as a fluid-saturated poro-elastic medium. Biot's theory of sound propagation in a porous elastic solid is attractive because it embodies the physical relationships between acoustic and geophysical properties but without the burden of computing stress and strain on a microscopic scale. Biot's theory has been successfully applied in specific cases, and can account for observed propagation phenomena that were beyond the capability of the simpler models. It has the potential of becoming the basis of a unified model for a wide variety of sediment types. Recent enhancements of the simpler fluid approximation, particularly the roughness scattering mechanism for propagating and evanescent waves, offer alternative models of the observed acoustic penetration phenomenon. The hypotheses are plausible. Computer simulations and laboratory experiments may be constructed to demonstrate them, but the extent to which they are applicable in ocean sediments is not known. The extant database of experimental measurements does not contain the necessary information to resolve the model differences. It is necessary to devise new experiments that will unambiguously quantify the relative merits of the competing models. The adopted approach is a program of laboratory and in-situ experimental investigations under realistic conditions to determine the applicability of each model and it's relative merits.

The candidate models of acoustic penetration include:
1. Biot slow wave
2. Scattering of in-water acoustic wave by sediment roughness
3. Scattering of evanescent wave by volume inhomogeneities

The models are expected to be discriminated by the predicted dependencies of acoustic penetration on a number of measureable acoustic and envirionmental properties. The experiments will involve acoustic scattering and penetration measurements through sediment surfaces of varying degrees of roughness.

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The following measurements are particularly relevant:

1. Pulse arrival time and attenuation in the sediment (buried array experiment):
Each model predicts pulse arrival times and signal attenuations in the sediment that are unique due to differences in the assumed mechanisms. In the case of the Biot model, the wave will be a slow wave, but in the scattering mechanisms, the wave will be a fast wave. These waves have different speeds and attenuations and may be measured with an array of buried acoustic sensors.

2. Ray-path through water-sediment interface:
Each model predicts a different raypath for the sound within the sediment. The Biot theory predicts a raypath that satisfies Snell's law but the scattering mechanisms do not. The differences may be detected using pencil beams.

3. Pulse coherence within the sediment:
The Biot model predicts a coherent pulse arriving as a slow wave, but the scattering models, due to the stochastic nature of scattering, would predict a signal of reduced coherence. A moving source will provide numerous paths, the statistics of which will give a measure of the signal coherence.

These measurements require the development of a precision buried acoustic sensing array and a mobile broadband sound source. Hardware in the sediment must be kept to a minimum to reduce the possibility of interference with the bottom penetrating waves. Methods of deployment and position estimation are needed to satisfy these requirements. Laboratory experiments can resolve specific issues and provide a testbed for at-sea experiments. Certain experiments are only practical in the laboratory because they require a degree of control over the environment that is not obtainable at sea, particularly those involving the adjustment of sediment surface roughness.

Cooperation with NRL, CSS, and other laboratories in the U.S., and laboratories abroad including the SACLANTCEN, and GESMA, has the potential of increasing the effectiveness of this project through the sharing of data and subsequent analysis results from related experiments.

WORK COMPLETED

A new hydrophone array design was developed. For practical reasons, previous buried arrays consisted of elements planted in vertical lines. Disturbance of the sediment at the intersection of the vertical line and the sediment interface causes scattering which may be mistaken for a slow wave, as demonstrated by Simpson and Houston (1996). The new array design contains elements arranged on a sloping rigid support, that enters the sediment at an oblique angle. Scattering from any disturbance at the intersection between array and sediment interface would appear outside the range of wave speeds of interest.

A self-burial mechanism was developed, using a small portable water pump, that allows the hydrophone array to penetrate the sediment under diver control. A small water jet at the tip of the line array causes the sediment to be locally liquified, allowing the array to slip into the sediment at any desired angle.

A new array processing algorithm was developed that has the ability to distinguish waves scattered by scatterers at the sediment interface and within the sediment volume, from waves from a distant source in

the water. The method uses focusing in addition to beamforming and wave speed searching to make the discrimination. It is possibly simpler and more robust than the inversion or tomographic methods currently being tested.

Plans were made for the first DRI seatest, including hardware system and software design, using existing and COTS equipment as far as possible for efficiency and economy.

RESULTS

The mechanical aspects of the new array design were successfully tested, in a preliminary test, in a sandy sediment, close to the University of Texas Marine Science Center, at Pt. Aransas, TX. From a previous measurement, the sand is known to have a mean grainsize of 2.5 phi, and a composition of 85% quartz sand, with the remainder made up mainly of shell fragments. The array was successfully inserted into the sediment with minimal disturbance of the surrounding medium.

The new array processing algorithm was successfully tested using simulated test data. Simulated signals originating from scatterers at the sediment interface and in the sediment volume were distinguishable from waves from a distant source point in the water. This capability will allow the candidate sediment penetration mechanisms to be separated and identified.

A sediment classification cruise was conducted to geologically characterize candidate sites off Panama City, Florida. The large population of colocated acoustic reflection and in-situ transmission measurements collected forms a very valuable data set from which inversion for Biot parameters may be made.

IMPACT/APPLICATION

The results will lead to the identification of the physical processes underlying the acoustic penetration of ocean sediments. The resulting model, which may be a combination of several physical processes, will accurately represent the acoustic interactions at the seafloor and will form the foundation of the next generation of buried mine detection and classification performance models, to the benefit of current and future sonar systems.

TRANSITIONS

The results will lead to improved models for buried mine detection, that are directly transitionable into a number of sound propagation and sonar models, including OASES, SWAT, BOGGART, MINERAY, and other models in which acoustic interaction with the ocean bottom must be accurately modeled.

RELATED PROJECTS

1 ñ Physics Of Offshore Buried Mine Detection and Classification. This project provided some of the theoretical ground work.

2 ñ Projects related to the application of the Biot model to sediment acoustics, such as Sediment Acoustics (Stoll), and Range Dependent Media (Stephens), will benefit from the findings in this project.

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